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A comparison of costs for indexable blade and brazed blade milling cutters

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A Comparison of Costs for Indexable Blade and Brazed Blade Milling Cutters

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TABLE OF CONTENTS

TABLE OF CONTENTS

(Continued)

APPENDICES

Introduction

The problem which gave rise to the topic of this thesis is the determination of the most economic way to rough mill die blocks. The operation consists of rough milling die blocks used in the forging industry. The shop is in the Drop Forge Department of the Bethlehem Steel Company. Open face milling and milling to a shoulder comprise the bulk of the milling operation. These are the two types of milling considered in this thesis.

Because of the requirements of the large quantity of metal removal and the subsequent finish operation there is no requirement as to smoothness or surface finish on the roughing cut.

The requirement is bulk metal removal done quickly and at least cost. The above two requirements may not occur simultaneously; therefore, both are investigated in this thesis.

The material cut is the commercially available Hardtem and Finkl die block steels. The analysis of the Hardtem blocks is C 50/55 Mn 60/80 Si 25/35 Cr 90/110 V 10 Ni 30/40 Mo 30/40. The analysis of the Finkl die blocks is V trace C 50/55 Mn 60/80 Si 20/30 Cr 1.00 Ni 1.00 Mo 30/35. The Hardtem and Finkl blocks are not exactly the same in machinability even though the hardness is rated in the same group. Hardtem A and Finkl 1 blocks have a hardness of 42 to 46 RC.

Hardtem B and Finkl 2, 37 to 40 RC and Hardtem C and Finkl 3, 32 to 36 RC.

The machine on which the milling is done is a 100 horsepower Ingersoll die block miller with a 16" diameter horizontal spindle. It is a solid bed type with 16 ft. long table and 14 ft. travel. The machine has infinitely variable spindle speed 20 to 145 rpm, and has table feed rates that are infinitely variable from 0.5 to 25 in. per minute.

The tool material is sintered tungsten carbide. High speed steel was not considered for many reasons, most of them are so obvious that they would be out of place in a thesis of this status. It is sufficient to say that some of the material cut approaches the hardness of the high speed steel tools themselves. Ceramics were considered and were investigated. None however were tested. At the time representatives of ceramic manufacturers assured me that ceramics had not been developed to the point of being able to make roughing milling cuts in hard steel economically. Ceramics were at the time being adapted to finish cuts both turning and milling. This is not to preclude a future improvement that would make a study of ceramic milling worthwhile.

The job operation is two-fold. One is to rough mill the worn out impression from the face of a die. This is a plain face milling job that varies in depth from ½" to 2" or more. The length and width of the blocks varies from small blocks of 12" by 16" to large blocks 36" by 48" face area. The second job operation is milling shanks on new die blocks. A shank is used as a means of securing the die in the forging hammer or machine. The shank is a dovetail protrusion at the bottom of the die block that can be wedged into the hammer with the aid of a key. The milling required to put the shank on a die block is always 2 1/4" deep and a width varying from 3" to 9" with a predominant width of 7".

Since about 75% of the milling done is shanking it was decided to favor this job in selecting the milling cutter.

Although the job done is a rather specialized application, it is felt that the results of the tests can be applied to most any rough milling job where bulk metal removal at the least cost is the issue. Of course, in an economics study all possibilities should be listed and checked out. It could be said that the most economical method of doing the job in this case would be eliminating the need for such heavy metal removal by forming the job piece closer to the finished size. This is true, and the proper approach to take, but in the case of milling shanks on die blocks it is not possible beforehand to determine the direction of the shank. Until the die layout is made a die block in the rough can be used with the shank running either way. A smaller inventory of expensive die blocks will then cover the most frequently used die sizes.

The results of the tests however can be applied to other roughing cuts. Although the tests were all conducted on steel of the same general analysis (a steel SAE No. 5150 closely approximates the steel used in the die blocks) the results can be indicative of results of tests on other steels. Using the machinability rating the results can be applied directly to other steels.

Past methods. For a number of years milling operations have been done with brazed carbide blade milling cutters. This type of cutter was and still is an improvement over high speed steel cutters. In this case, which is the subject of this thesis, brazed blade carbide milling cutters were used. A procedure was set up to have these cutters ground when dull and repaired when blades were broken and/or worn down to the limit. A fully developed methods analysis of the past methods is discussed on Page 5.

Present methods. Around 1955 a number of cutting tool manufacturers developed and began to perfect the indexable blade milling cutter. Probably the first one to have a successful cutter on the market was Futur Mill, a division of Detroit Milling Cutter. The principal behind the indexable blade or "throwaway blade" milling cutter is simply the elimination of grinding the cutter by having the blades furnished finished ground to a close tolerance. Then, because the blade (a piece of solid carbide usually square in shape) is held in the cutter with some sort of convenient wedging arrangement it can be easily indexed when dull. The cutter need not be taken off the machine. By simply indexing the blades so that a fresh cutting edge is exposed a "new" cutter is ready to go.

At first glance some possible savings that might be expected using indexable blade milling cutters would be lower investment cost in cutter bodies and elimination of grinding costs. This topic is covered more fully on Page 13.

Development of Past Methods

Brazed Blade Cutters. Twelve brazed blade cutter bodies were supplied for the milling machine at a cost of about $9900 or $825 average cost per cutter. There were four different cutters, three of each kind. The difference was in diameter and maximum depth of cut possible. In the past all cutters used the brazed blade with an average cost of the blade being about $5.25.

Two different blades were needed to supply the four different cutters. An inventory of 50 blades of each type was kept on hand at all times. It required an average of 16 blades per cutter. There were occasions when all the blades on a cutter would be smashed or broken due to operator error. A delivery time of one month was standard on brazed blades.

Maintenance of Brazed Blade Cutters. The cutters were ground on two Ingersoll tub type grinders. The roughing operation was on one grinder with a 60 grit silicon carbide (green) wheel. The finish grind was done on the second grinder with a 300 grit diamond wheel. The number of regrinds on each blade varied greatly because of breakage of some of the blades. But the average number of regrinds would be nine on the blades that were designed for the 1/2" deep cuts and 4 regrinds for the blades designed to cut 1 1/8" deep.

The time to grind a cutter averaged 1 1/2 hours, some cutters could be ground in 45 minutes others took as long as 2 1/2 hours (when the blades needed changing). The regrind cost was charged by the hour with an hourly rate including material cost and overhead of about $8.00 per hour. There may be some question as to the reasonableness of charging full overhead. In this case we must because the grinding was done in another shop and the die shop was billed monthly for so many hours at just such a rate.

Cutter Life (Actual). Brazed blade cutter life varied from cutter type to cutter type and also varied with the hardness of the die blocks. The life of the blades designed to cut 1/2" deep was approximately 2000 square inches at 1/2" deep and under. The life of the cutters designed to cut 1 1/8" deep was about 850 square inches at 1 1/8" deep. The cutter was changed when flank wear was between .020 and .025. Volume wise the two types of cutters cut about the same as can be seen from the above figures (about 1000 cubic inches). However, the cutter designed to take the deep cut was usually chipped or broken and in much worse shape after cutting. This required a great deal more stock removal in the grinding operation to bring it back to a sharp condition. Hence, the average of four regrinds per blade.

Surface Finish. The surface finish on the work piece was very good considering the fact that surface finish is not in the least bit critical. Normally a surface roughness of 125 u inches RMS was achieved with brazed blade cutters.

Tool Life for Minimum Cost. In the calculations of tool life and tool cost only the cutter designed for 1/2" deep cut will be considered. It is felt that since the blades for the deep cut are more expensive in original cost and only get four regrinds per blade the total cost picture will not be as favorable as for the cutter with 1/2" depth of cut.

Using the Tool life, for minimum cost, equation (11, Page 315):

$$T_{\text{min.cost}} = (1/n - 1)\,\frac{\text{Tool replacement cost (\$ per cutter)}}{\text{Labor + overhead rate (\$ per min.)}}$$

where $T_{\text{min.cost}}$ = tool life in minutes (at min.cost)

n = exponent of the tool life cutting speed equation $VT^n=C$

Tool replacement cost = sum of the three following:

Tool changing cost = tool changing time x (labor rate + overhead rate)

Tool grinding cost = grinding time x (grinders rate + overhead rate)

$$\text{Blade cost} = \frac{\text{cost/blade x no.of blades in cutter}}{\text{no. of grinds}}$$

a tool life, at minimum cost, of 667 minutes or 11.1 hours is determined (See Appendix A) for brazed blade cutters.

<u>Cost per Unit Milled.</u> The cost per unit amount of milling (in this case 2000 sq. inches shall be the unit amount*) includes the following four separate costs:

*The reason 2000 sq. inches was selected as the unit amount of metal cut is because this is the average life of the brazed blade cutter and it is also the approximate amount of metal cut in milling an average size block.

1. Idle cost per piece. This includes time to reset each pass, tool approach, tool over run etc.

2. Cutting cost per unit (2000 sq. inches) This includes labor and overhead rate times the actual cutting time.

3. Tool changing cost per unit (2000 sq. inches). This is the tool changing time multiplied by the labor and overhead rate.

4. Tool replacement cost per unit (2000 sq. inches). This is the original cost divided by the number of regrinds plus regrind cost.

Summing up the four above costs for brazed blade milling cutters a cost of $29.18 is realized. This is the cost for the cutter designed to cut 1/2" deep. The cutter designed for 1 1/8" depth of cut, although not calculated, would have a cost at least twice as great.

Extra Costs. Not considered here were some costs peculiar to the shop such as the cost of manifesting and transporting the cutters to a distant shop to have them ground. Normally the grinding would be done near the area where the cutters are being used. However, not to be forgotten is the definite cost of handling these cutters as well as the cost of capital tied up in the cutters needed to fill the pipe line, so to speak, between machine and grind room. This last cost is especially apparent when comparing it with the next study that of indexable blade cutters.

For general information the die miller had been operating on one turn per day, five days a week, with an average monthly grinding bill (exclusive of new blade cost) of $450. This extended over a controlled period of about 8 months. At the time, the cutting time to cut one unit (2000 sq. inches) was about 150 minutes.

Development of Present Methods

Selection of Cutter Type. At the start of this analysis it was necessary to purchase an indexable blade milling cutter to run the tests and gather data for the economic study. At this time there were quite a few cutter body manufacturers that had indexable blade cutters on the market or in development. In order to decide which milling cutter was the best, a number of companies were invited to bring in their cutters for test on our machine.

The following companies responded and had cutters tested:

1. Futur Mill (negative radial, negative axial rakes)

2. Goddard and Goddard (negative radial, negative axial rakes)

3. Goddard and Goddard (negative radial, positive axial rakes)

4. Lovejoy (positive radial, positive axial rakes)

5. Nucommer (negative radial, negative axial rakes-using both triangular and square blades)

6. Pratt & Whitney (negative radial, negative axial rakes)

7. Wesson (negative radial, negative axial rakes)

One of the first considerations when selecting an indexable blade cutter is the radial and axial rakes. When the radial and axial rakes are each negative (commonly called double negative) the blades can be indexed eight times. On all the other combinations the indexability is cut down normally to four. This immediately indicates a factor of 2 in the possible blade cost. One might say that the decision is apparent and in favor of the double negative. This is not always the case due to other considerations.

Generally, though, if the material that is to be cut allows the use of double negative, then double negative is the most economical. Some reasons why double negative may not be the best are:

1. Cut too wide. When the width of the cut becomes more than eight inches at 1/2" depth there

is difficulty getting the chip out of the pocket. It tends to bunch up in the chip pocket and stay there till the next go around, this tends to break the blade. Not so with negative radial, positive axial cutters where the angle of inclination (12, Page 308) is positive and the chip tends to curl out and away from the work piece and cutter. This was found to be an important consideration. Except for the fact that a special double negative cutter with an extra large chip pocket was tested and accepted, the decision would have had to go to the four indexes per blade.

2. Work piece very thin. Although this was not an issue in our testing it was recognized that double negative cutters bring about the greater pressures on the work piece. If a thin work piece is the considered job then any of the other type cutters may be better.

3. Lack of sufficient power. The double negative cutter requires up to 25% more power than the other designed cutters. Although this was not of concern here because of the ample power available it may be of concern on smaller machines. A 12 inch diameter double negative cutter with 16 teeth cutting 5/8 inch deep in die block B material with an 8 inch width at 6 inches per minute feed

draws about 45 horsepower.

Cutter Selected. It is not the purpose of this thesis to sell or promote a certain make of cutter. The intent of mentioning the names of different companies was to make available a list of good milling cutters available on the market. For our particular job we selected Futur Mill. Under another set of circumstances one of the others may have been better. The purpose of this thesis is to evaluate indexable blades which follows.

Cutter Body and Blade Maintenance. Two indexable blade double negative 12" diameter cutter bodies were purchased at a cost of $1300 or $650 per cutter. The cutters were identical except for the fact that one cutter took a one inch square blade and the other a .950 inch square blade.

A short explanation is necessary here to explain the difference in the size of the blades. When a blade has been indexed eight times and is dull on all eight cutting edges normally the blade would be thrown away. However, the cost of a one inch square 5/16" thick solid carbide blade is great enough to make it economical to have the blade reground. There are companies that will regrind your used blades by taking .025 inch off each side (hence .950).

The blade price new is very competitive and runs anywhere from $3.50 to $4.95 for a one inch square 5/16" thick precision ground blade. Precision ground blades are required in order to insure holding the run-out to a minimum. Regrind price for this blade runs $1.50 to $2.00.

The cutter selected has 16 blades. It was thought at the time that the one style cutter would replace the two styles of brazed blade cutters. After testing and using the cutter for six months in every day production use this proved correct.

The reorder lead time for these blades approached six weeks, therefore, a 75 blade reorder point was used.

The most common blade size on the market for this type of milling is 3/4" square. A one inch square blade was selected because 5/8" depth was desired. To cut 2 1/4 total depth can be done with 5 passes at 1/2" or 4 passes at 5/8". Thus one pass is eliminated. A cut 3/4" deep proved to be too much for a one inch blade. To cut 5/8" deep in hard steel required the larger blade both for extra strength in the blade and for the added chip pocket size so necessary on the wide cuts.

Cutter Life (Actual). The cutter life on the indexable blade cutter varied with the hardness of the die blocks. The life of the cutter for one index averaged between 2500 and 3000 sq. inches at depths ranging from 1/4 to 5/8 inch. The average depth is about 1/2". The life of the blade varies because of the mixture of the different hardness die blocks. This too would represent a volume of about 1250 to 1500 cu. inches of steel milled per cutter. The type of blade used was of the general purpose steel cutting grade as it was in the brazed blade tests.

Indexability. A feature of the indexable blade cutters that was not apparent at the start is the possibility of indexing one blade or two blades without indexing all the blades. The value of this was not apparent until the first blade chipped out (this happens occasionally with indexable blades as well as with the brazed blade type cutter). With the brazed blade type cutter if a blade chips or breaks, as it does occasionally, the cutter must be taken off the machine and sent back to the grinding room. Here all the blades whether dull or not will have to be ground down to the broken or chipped blade size. This may not be necessary if the tool grinder moves out the broken blade but at least some grinding will be required to true the cutter.

With the indexable blade cutter, if a blade is bad for one reason or another, that one blade is indexed or replaced and the cutter is repaired. This is reflected in the overall average blade life because there would be a tendency for each of the blades to approach the .020 to .025 flank wear before being indexed. There is a slight bit more time taken to index 16 blades in one's and two's than when doing all 16 at a time. Because of the price of the blade the extra blade life savings outweighs the loss in tool changing time.

__Surface Finish.__ The surface finish is poor but for roughing cuts it is adequate. The surface roughness varied depending on the care in indexing the blades but it was normally around 500 u in. RMS. Since these were roughing cuts and since a finish cut to put a 5 degree angle on the shank is necessary this roughness was acceptable.

__Tool Life for Minimum Cost.__ In the calculations for tool life and tool cost a 5/8 inch depth of cut was considered. This depth is used mostly when roughing the shank. Of course depth would have an effect on tool life.

Using the Tool life for minimum cost equation again:

$$T_{min.cost} = (1/n - 1)\frac{\text{Tool replacement cost (\$per cutter)}}{\text{Labor + overhead rate (\$per min.)}}$$

Note: explanation of terms used in equation on Page 7 determines a tool life at minimum cost of 255 minutes or 4.25 hours.

Cost per Unit Milled. The cost per unit amount of milling (2000 sq. inches) again includes the four items of cost cited on Page 8. The total cost is $14.08. This is the cost of the indexable blades running at the speed to give a tool life of 150 minutes. The testing extended over a period of about four months.

Coolant. Another significant development from the tests was the determination that the blade life increases when using a spray mist coolant. Some tests were run dry and others with a mixture of water and soluble oil sprayed in a mist form on the blades as they enter the cut.

The spray, however, has one detrimental effect. As the cutter cuts through scale and rust the oily film left by the spray holds the dust and tends to clog up the blade seats and wedge screws. The operator must at times take time and clean the milling cutter body with a high pressure air line.

Radius. The radius of the blades also greatly affects the life of the cutter. Some cutter manufacturers recommend using a chamfer on the corner instead of a radius. When a chamfer is used it is usually 1/16 to 1/8" in size. When using a radius 1/16" is the standard size.

Carbide Grade. There were a number of different grades of carbide tested. The three general groups, non-ferrous, general purpose steel cutting and premium steel cutting were all tested. Different manufacturers of carbide have different mixtures of the elements, tungston carbide, cobalt, titanium carbide, and tantalum carbide. Along with the alloying elements, grain size is important and affects the cutting characteristics. Carbides from Adamas, Carboloy, Firth Loach, Firth Sterling, and Walmet were tried.

Carbide blades are highly competitive in price and one would do well to shop around, so to speak, for the best buy. For after all, if a business is to run as economically as possible all considerations must be investigated. Due to the fact that non-ferrous grades of carbide are usually 10 to 15% cheaper than the general purpose steel cutting grade this too should be investigated and was in the tests.

Recommendations for Further Study.

1. With reference to the exponent "n" in the cutting speed formula the values of "n" normally found in publications were compiled from turning operations. It is felt that "n" is not a constant but varies with the environment of the cutter and work piece. And it is also felt that "n" also varies with the hardness of the work piece. Therefore, there is a need for investigations into the effect on "n" when milling with different elements considered.

2. The feed and depth of cut variables need more accurate and inclusive tables of exponents for milling. The exponents in the equation of tool life and depth and feed rate do not appear to be constants. ($V = \frac{C}{d^x f^y}$)

Conclusions.

It is true that minimum cost milling would require the maximum depth of cut with a maximum feed rate. In practice, however, depth of cut and feed rate are very sharply limited by other features in the milling job. The depth of cut is limited by power available, size of blade, design of cutter, etc. As the depth of cut is increased the cost of the blade rises considerably because not only does the area of the blade increase but also the thickness.

Feed also affects the overall cost in a number of ways including speed and blade thickness. The tests for economic tool life were all conducted at a .006 to .010 inch feed per tooth. This is a reasonable feed rate for roughing cuts. If increasing the feed rate would not change the tool geometry and bring about chipping then a higher feed would be more economical.

A comparison of the costs per unit of material milled:

Brazed blade cutter - $29.18 per unit

Indexable blade cutter - 12.68 per unit

Indicates that brazed blades milling costs over 230% of the indexable blade milling. On a yearly basis this could mean a saving of $3750 on operating expense alone.

A consideration of the elements of the above costs reveals that the bulk of the savings is due to the elimination of all the grinding costs.

	Brazed Blade	Indexable Blade
Idle cost	$ .98	$ .78
Cutting cost	6.50	5.20
Tool change	1.30	1.30
Tool replacement	8.40	5.60
Tool grind	12.00	0.00
Total	$29.18	$12.68

With savings such as these, justification can be easily compiled. But the operating expenses are not the only savings. The capital investment in tooling for brazed blades was $9900 whereas for indexable blade milling cutters it was $1300. It must be admitted that the planning at the outset was on the ultra conservative side to have 12 mills of four different sizes. Possibly two sizes would have been sufficient with a possible six or eight total cutters purchased. This would cut the investment to about $7000. Even then interest on the savings on investment at this level would be $350 per year.

The indexable blade cost was considered in the calculations to be $3.50 per blade. Greater savings will be realized when the regrind price is averaged with the initial price. The cost per blade becomes $2.50 which would reflect a saving in tool replacement cost of $1.60 more per cutter.

Another saving that will be mentioned, but not calculated, is the elimination of the transporting of the cutters to the grinding room. The reason for just mentioning and not calculating it is that other shops may have their grinding rooms as an integral part of the shop and this would take on less importance in that case.

The tests have also indicated that conventional or up milling increases the blade life in comparison to climb or down milling. In milling, which is always an interrupted cutting operation, the carbide blade takes a shock as it enters the work piece on each and every rotation. When the steel is hard as it was in these tests there is a tendency for chipping at the cutting edge. The blade would fail before it would be worn out. With conventional cutting there is possibly more wear per unit of material cut but at least the blades last long enough to reach the point of maximum wear.

The tests have also indicated that the radius of the blade affects the tool life. Tests with 1/32 were complete failures with the corner failing almost immediately on a 5/8 inch deep cut. Radii of 1/16, 3/32 and 1/8" faired better with 3/32 being the best for this depth of cut at the feed and speed constant.

A number of different grades of carbide were tested. It was found that the general purpose steel cutting grades cut just about as much as the premium grades and the non-ferrous grades tended to fail prematurely due to cratering. Therefore, the general purpose steel cutting grades would be the selection here.

APPENDIX A

Summary of Data

Material	Brazed Blade Sq.In.	Brazed Blade %	Indexable Sq.In.	Indexable %
F1	13,925	16.6	11,162	14.1
F2	41,807	49.8	39,174	49.3
F3	6,875	8.2	10,072	12.6
HA	720	0.8	0	0
HB	19,037	22.6	15,815	20.0
HC	1,592	1.9	3,276	4.1
Total	83,956	99.9	79,499	100.1

	Brazed Blade	Indexable
No. of cutters Used	41	31.1*
Avg. Cutter Life in Sq. In.	2,040	2,560

* 497 indexed blades @ 16 per cutter = 31.1 cutters

APPENDIX B

Calculations for Tool Life

For Brazed Blade Milling Cutter

For minimum cost

$$T_{\text{min.cost}} = (1/n - 1) \times \frac{TRC}{K_1}$$

$$TRC = \frac{(\$5.25/\text{blade} \times 16\ \text{blades})}{10\ \text{uses}} +$$

$$(1\ 1/2\ \text{hrs.} \times \$8/\text{hr.}) +$$

$$(10\ \text{minutes} \times \$.13/\text{minute})$$

$$= \$8.40 + \$12.00 + \$1.30 = \$21.70$$

$$K_1 = \$.13/\text{minute}$$

$$T_{\text{min.cost}} = (1/.2 - 1) \times \frac{\$21.70}{\$.13} = 667\ \text{minutes}$$

$$= 11.1\ \text{hours}$$

For maximum production

$$T_{\text{max.prod.}} = (1/n - 1) \times \text{Tool changing time}$$

$$= 4 \times 10 = 40\ \text{minutes}$$

For Indexable Blade Milling Cutter

For minimum cost

$$T_{\text{min.cost}} = (1/n - 1) \times \frac{TRC}{K_1}$$

$$TRC = \frac{(\$3.50/\text{blade} \times 16\ \text{blades})}{8\ \text{uses}} +$$

$$(10\ \text{minutes} \times \$.13\ \text{minute})$$

$$= \$7.00 + \$1.30$$

$$= \$8.30$$

TGC = 0

$$T_{min.cost} = (1/.2 - 1) \times \frac{\$8.30}{\$.13} = 255 \text{ minutes}$$

$$= 4.25 \text{ hours}$$

For maximum production

$$T_{max.prod.} = (1/n - 1) \times \text{Tool changing time}$$

$$= 4 \times 10 = 40 \text{ minutes}$$

APPENDIX C

Calculations for Cost

For Brazed Blade Milling Cutter

Total cost = Idle cost + Cutting cost + Tool changing cost + Tool regrind cost

Idle cost = 10 passes x (.5 minutes reset/pass + .25 minutes $\frac{\text{approach \& exit}}{\text{pass}}$) x $.13/minute

= $.98

Cutting cost = 10 passes x 5 minutes/pass x $.13/minute

= $6.50

Tool changing cost = 10 minutes x $.13/minute

= $1.30

Tool regrind cost = $\frac{(\$5.25/\text{blade x 16 blades})}{\text{10 uses}}$ + (1.5 hours x $8/hr.)

= $20.40

Total Cost = $29.18

For Indexable Blade Milling Cutter

Idle cost = 8 passes x (.5 minutes reset/pass + .25 minutes $\frac{\text{approach \& exit}}{\text{pass}}$) x $.13/minute

= $.78

Cutting cost = 8 passes x 5 minutes/pass x $.13/minute

= $5.20

Tool changing cost = 10 minutes x $.13/minute

= $1.30

Tool repair cost = $\frac{\$3.50/\text{blade} \times 16 \text{ blades}}{8 \text{ blades}} \times \frac{2000 \text{ (sq.in./unit)}}{2500 \text{ (sq.in.)}}$

= $5.60

Total Cost = $12.68

APPENDIX D

Brazed Blade Data

DATA

Type of cutter: Ingersoll Blade: Brazed Blade Grade: 78B

Dia. of cutter: 12" No. of teeth: 18 Corner angle: 30°

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Regrind
1	F2	6	40	1/4	7	38	4	1060	-
2	"	"	"	"	"	24	4	672	Yes
3	"	6½	"	5/8	5½	38	6	1255	-
4	"	"	"	1/2	"	"	2	418	-
5	"	"	"	1/8	10	"	1	380	-
6	F1	4½	33	"	6	11½	2	136	-
7	"	"	"	1/4	"	"	5	338	Yes
8	F2	6	40	5/8	5½	38	2	418	-
9	F1	4½	33	1/8	6	11½	3	203	-
10	"	"	"	1/4	3	"	8	270	-
11	F3	6	40	5/8	5½	38	4	836	Yes
12	"	"	"	1/8	10	"	1	380	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Regrind
13	H3	6	40	1/2	5½	38	2	420	-
14	"	"	"	5/8	5	"	2	380	-
15	"	"	"	"	7	"	2	535	-
16	"	"	"	3/8	5	"	2	380	Yes
17	HB	"	"	1/4	7	30	4	840	-
18	"	"	"	"	"	26	4	730	-
19	"	"	"	"	10	30	1	300	-
20	"	"	"	5/8	8	"	1	240	Yes
21	"	5	"	"	"	"	1	240	-
22	"	"	"	1/2	"	"	3	720	-
23	"	"	"	3/16	10	"	1	300	-
24	"	6	"	1/4	8	"	1	240	-
25	"	4	"	1/2	6	"	1	180	-
26	"	"	"	3/8	"	"	1	180	Yes
27	"	4½	33	1/4	3	52	2	312	-
28	F1	"	35	3/16	5	12	1	60	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Regrind
29	F1	4½	35	3/16	3	12	1	36	-
30	"	"	"	3/8	"	"	1	36	-
31	"	5	"	3/16	10	18	2	360	-
32	"	"	"	"	14	"	2	503	-
33	"	"	33	5/8	5½	14	3	231	Yes
34	"	"	"	1/4	7	"	1	98	-
35	F2	6	38	5/8	3	16	3	144	-
36	"	5	"	1/2	3½	"	4	224	-
37	"	"	"	1/4	"	"	1	56	-
38	F1	"	33	1/16	5	12	3	180	-
39	"	"	"	1/8	"	"	1	60	-
40	"	7	45	"	3	56	2	336	-
41	"	"	"	1/4	"	"	3	504	Yes
42	"	"	"	1/8	2¼	34	3	234	-
43	"	"	"	1/4	"	17	2	76	-
44	F2	6	38	"	7	30	4	840	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Regrind
45	F2	6	38	1/4	7	24	4	672	-
46	"	"	35	5/8	9½	30	6	1710	Yes
47	"	"	"	1/4	10	"	1	300	-
48	"	"	"	1/2	9½	23½	3	670	-
49	H1	"	"	"	2	30	6	360	-
50	"	"	"	"	"	23½	3	141	Yes
51	F2	"	38	1/4	7	11	4	658	-
52	"	"	"	5/8	8	26	4	830	-
53	"	5	45	1/8	10	"	1	260	Yes
54	"	"	"	5/8	8	"	12	2500	-
55	"	6	"	1/4	10	"	1	260	-
56	"	"	33	1/4	6½	30	1	202	Yes
57	"	"	"	5/8	"	"	5	974	-
58	"	"	"	1/8	"	"	1	195	-
59	HA	5	38	1/2	5½	12	4	264	-
60	"	"	"	"	9½	"	4	456	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Regrind
61	F1	5	35	3/16	6	12	2	144	Yes
62	"	"	"	3/8	"	"	4	288	-
63	F2	5½	45	5/8	8	27	8	1730	Yes
64	"	"	"	1/8	10	"	1	270	-
65	H3	6	"	1/4	7	26	8	1460	Yes
66	"	5½	"	5/8	7½	"	8	1610	-
67	"	"	"	"	6	"	8	1250	Yes
68	"	"	"	3/16	10	"	2	520	-
69	"	5	33	"	8¼	50	1	412	-
70	"	"	"	"	6	"	2	600	Yes
71	"	"	"	1/4	5	"	4	1000	-
72	"	"	"	"	3	"	2	300	-
73	H4	6	45	1/4	8	12	2	192	-
74	"	5½	48	5/8	7	20	4	560	Yes
75	"	4½	40	1/4	12	26	2	624	-
76	"	"	"	"	"	18	1	216	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Regrind
77	F1	4	35	1/4	10	14	2	280	-
78	"	"	"	"	"	10	2	200	-
79	"	"	"	5/8	3½	20	6	420	Yes
80	"	"	"	3/8	3	"	2	180	-
81	HE	6½	50	5/8	8	36	5	1440	Yes
82	"	"	"	1/2	"	"	5	1440	-
83	"	"	"	1/4	10	"	1	360	-
84	F3	7	55	"	8	24	2	384	Yes
85	"	"	"	"	"	40	2	640	-
86	"	6	40	1/2	7	"	2	560	-
87	"	"	"	"	10	"	1	400	Yes
88	"	"	"	5/8	7	"	7	1960	-
89	F2	5½	45	1/2	8	12	9	864	-
90	"	"	"	3/8	"	"	2	192	Yes
91	"	"	"	3/16	6	"	4	288	-
92	"	"	"	3/8	5	"	4	240	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Regrind
93	F2	5½	45	3/8	3	12	4	144	-
94	"	"	"	1/4	8	31	1	248	Yes
95	"	"	"	"	6	"	2	372	-
96	"	"	"	3/8	"	"	2	372	-
97	"	"	"	"	4	"	2	248	-
98	"	"	"	"	3	"	2	186	-
99	H3	6	48	1/8	"	14	1	42	Yes
100	F2	5½	45	1/4	7	24	4	672	-
101	"	"	"	5/8	"	"	6	1010	Yes
102	"	"	"	1/4	10	"	1	240	-
103	"	"	"	3/8	7	"	4	672	-
104	"	"	"	9/16	8	16	6	770	Yes
105	F1	4½	40	1/4	7	25	4	700	-
106	"	"	"	5/8	8	24	6	1150	-
107	"	"	"	3/8	"	"	3	577	-
108	"	5	"	1/16	5	12	8	480	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Regrind
109	F1	5	40	3/16	5	12	4	240	Yes
110	HB	6	"	1/4	10	18	8	1440	-
111	"	"	"	1/2	9	"	8	1300	Yes
112	F1	4½	"	5/8	6½	24	2	300	-
113	F2	5½	45	1/4	7	26	8	1450	Yes
114	HB	"	"	"	"	22	2	308	-
115	"	"	"	5/8	6	"	6	791	-
116	"	"	"	1/2	"	"	2	262	-
117	"	"	"	1/8	10	"	1	220	Yes
118	F2	5	"	5/8	6	48	10	2880	Yes
119	"	"	"	1/4	10	"	3	1440	-
120	"	"	"	3/8	6	"	2	575	Yes
121	"	6	"	5/8	4½	28	2	252	-
122	"	"	"	1/2	7	"	3	589	-
123	"	5½	"	"	6	"	4	670	Yes
124	F1	4½	38	1/4	5	12	4	240	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Regrind
125	F1	4½	38	1/8	5	12	2	120	-
126	F2	4	45	1/4	12	28	3	1000	Yes
127	"	5	40	5/8	6½	"	10	1820	-
128	"	"	"	1/4	9	"	1	252	Yes
129	"	5½	"	5/8	6	"	2	336	-
130	"	"	"	1/2	"	"	5	840	-
131	F1	4½	38	1/8	8	12	4	284	-
132	F2	6	45	1/4	7	22	4	615	Yes
133	"	"	"	5/8	6	"	10	1320	-
134	"	"	"	1/8	10	"	2	264	-
135	F3	4½	35	3/8	8	12	24	2300	Yes
136	"	"	"	1/4	6¼	51	2	638	-
137	"	"	"	1/8	12	"	1	612	-
138	"	"	"	3/8	3	"	2	306	-
139	"	"	"	1/4	"	"	2	306	Yes
140	F2	6	55	1/2	10	14½	2	290	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Regrind
141	F2	6	55	5/8	10	14½	2	290	-
142	"	9	"	3/8	"	"	2	290	-
143	"	"	"	1/4	8	22	2	352	-
144	"	"	"	"	"	20	2	320	-
145	"	6	"	3/4	5	"	1	100	-
146	"	"	"	5/8	"	"	6	600	Yes
147	"	"	"	3/16	"	"	1	100	-
148	"	8	"	1/8	7	24	2	336	-
149	"	"	"	1/4	"	22	2	308	-
150	"	"	45	5/8	"	"	7	1078	-
151	"	"	"	3/8	"	"	1	154	-
152	"	"	"	1/4	"	"	1	154	-
153	"	"	"	"	8	"	1	176	Yes

APPENDIX E

Indexable Blade Data

DATA

Type of cutter: Futur Mill   Blade: 1" sq x 5/16" thick   Grade FT4

Dia. of cutter: 12"   No. of teeth: 16   Corner angle: 15°

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
1	F1	6	60	5/8	7½	11¼	1	84	-
2	"	"	50	"	"	"	1	84	-
3	"	"	40	5/8	"	"	2	168	16
4	"	"	"	"	"	"	1	84	-
5	"	10	"	1/8	"	"	2	168	-
6	"	6	"	5/8	"	"	1	84	-
7	"	7	35	"	"	"	3	252	16
8	"	5	"	1/4	9	"	4	400	-
9	"	"	"	1/8	"	"	1	100	-
10	"	"	"	3/32	"	"	1	100	16
11	"	4½	"	1/4	"	"	5	500	-
12	F2	10	55	"	7	11	4	308	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
13	#2	10	55	1/8	7	11	2	154	-
14	"	"	"	"	8	24	1	192	-
15	"	"	"	"	10	"	1	240	-
16	"	6	"	5/8	8	"	1	192	-
17	"	7½	"	"	"	"	1	192	16
18	"	8	"	"	"	"	3	576	-
19	"	"	"	3/8	"	"	1	192	-
20	"	10	"	1/2	"	"	1	192	-
21	"	"	50	1/8	"	"	1	192	-
22	"	"	"	"	10	"	1	240	-
23	"	8	"	5/8	8	"	1	192	-
24	"	"	55	"	"	"	6	1152	-
25	"	10	"	3/8	"	"	1	192	16
26	#1	8	50	5/8	7	"	3	504	-
27	"	"	"	5/16	8	"	1	192	-
28	"	"	40	5/8	6	"	1	144	-

Test No.	Material	Feed in/min	Speed rpm	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
29	P1	8	40	1/2	5	24	1	120	-
30	"	"	"	5/16	7	"	1	168	-
31	"	"	"	1/2	8½	"	2	408	-
32	P2	"	50	1/8	10	26	1	260	-
33	"	"	"	"	8	"	1	208	-
34	"	"	"	5/8	"	"	6	1248	16
35	"	"	"	3/8	"	"	1	208	-
36	"	"	"	1/2	"	"	1	208	-
37	HC	12	60	1/8	10	20	1	200	-
38	"	"	"	"	8	"	1	160	-
39	"	9	"	5/8	10	"	2	400	-
40	"	7	50	"	"	"	4	800	-
41	P2	8	55	1/4	7	26	4	728	16
42	"	"	"	"	"	32	4	896	-
43	"	"	"	"	8	"	1	256	-
44	"	"	"	"	10	"	1	320	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
45	F2	7	45	5/8	8	32	7	1792	16
46	"	"	"	3/8	"	"	1	256	-
47	"	6	"	3/16	"	"	1	256	-
48	"	"	"	"	10	"	1	320	-
49	"	"	"	5/8	8	"	7	1792	16
50	"	"	"	3/8	"	"	1	256	-
51	"	$6\frac{1}{2}$	"	1/8	9	"	6	1728	-
52	HB	"	"	1/4	6	20	2	240	-
53	"	"	"	"	"	22	4	528	-
54	"	"	"	"	"	20	2	240	16
55	"	6	"	3/16	10	"	1	200	-
56	"	"	"	"	5	"	1	100	-
57	"	"	"	5/8	"	"	2	200	-
58	"	"	"	1/4	"	"	1	100	-
59	"	"	"	3/4	"	"	1	100	-
60	"	"	"	5/8	7	"	4	560	6

44.

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
61	#B	6	45	1/8	5	20	1	100	-
62	"	"	"	"	10	"	1	200	-
63	"	"	"	5/8	5	20	1	100	-
64	"	"	40	38	"	"	1	100	-
65	"	"	"	5/8	"	"	6	600	3
66	"	"	"	1/8	11	"	2	440	-
67	#2	"	"	"	7	24	1	168	-
68	"	"	"	"	10	"	1	240	-
69	"	"	"	5/8	7	"	1	168	1
70	"	5	"	"	"	"	2	336	-
71	"	6	"	3/8	"	"	1	168	-
72	"	5	"	5/8	"	"	4	672	10
73	"	6	"	1/8	"	"	1	168	-
74	"	"	"	"	10	"	1	240	-
75	"	"	"	5/8	7	"	7	1176	-
76	"	"	"	3/8	"	"	1	168	6

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
77	F1	4½	35	3/16	5½	52	1	286	-
78	F2	6	40	1/8	7	25	4	700	-
79	"	"	"	"	10	24	1	240	3
80	"	5	"	5/8	5½	"	8	1056	2
81	"	"	"	"	5	"	4	480	1
82	F1	4	33	5/16	6¼	11½	2	144	2
83	"	"	"	1/8	"	"	3	216	1
84	HC	6½	43	3/8	8	22	2	352	-
85	"	"	"	"	5½	"	4	484	-
86	"	6	"	9/16	10	"	4	880	10
87	F1	4	30	1/8	6	52	2	624	-
88	"	"	"	3/8	2½	"	1	130	-
89	"	"	"	"	5	"	1	260	-
90	"	"	"	5/8	2½	"	1	130	3
91	"	"	"	1/2	3	"	2	312	-
92	"	"	"	3/8	½	"	2	39	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
93	F2	6	35	1/4	7	26	4	728	-
94	"	"	"	3/8	"	"	4	728	-
95	"	"	"	1/8	10	"	1	260	2
96	"	5	"	5/8	8	"	4	832	16
97	"	6	40	5/8	8	"	2	416	-
98	"	"	"	1/2	"	"	2	416	-
99	"	5	"	5/8	"	"	1	208	3
100	"	"	"	9/16	"	"	3	624	5
101	"	6	"	1/4	5	"	2	260	-
102	"	"	"	5/8	8	"	3	624	2
103	"	5	"	"	"	"	2	416	1
104	"	6	"	1/2	"	"	1	208	-
105	"	"	"	1/4	"	"	1	208	16
106	F1	4	25	3/16	6¼	42	1	262	-
107	"	"	"	1/4	6	"	2	504	-
108	HB	6	37	"	"	18	4	432	6

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
109	HB	6	37	1/4	6	24	4	576	2
110	"	5	40	3/4	"	18	3	324	1
111	"	6	"	1/8	10	"	1	180	-
112	"	"	"	"	6	"	1	108	-
113	"	5½	"	5/8	8	"	4	576	-
114	"	"	"	"	6	"	4	432	3
115	"	"	"	"	8	"	4	576	-
116	"	"	"	3/16	10	"	1	180	11
117	Fl	4	30	1/4	6	12	1	72	-
118	"	3½	"	3/8	"	"	11	792	4
119	HB	6	40	1/4	"	24	4	576	-
120	"	"	"	"	"	14	4	336	3
121	"	5	"	5/8	"	"	8	672	13
122	"	"	"	"	8	"	8	896	-
123	"	6	"	1/4	10	"	2	280	-
124	Fl	4	30	1/8	"	12	1	120	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
125	F1	4	30	1/4	6	12	2	144	3
126	"	"	"	"	3	10	8	240	-
127	"	"	"	3/16	6	36	2	432	-
128	"	"	"	1/4	3	"	2	216	-
129	"	"	"	3/8	"	"	5	540	8
130	F2	6	40	1/4	6	16	4	384	-
131	"	"	"	"	"	25	4	600	9
132	"	"	38	"	7	24	4	672	-
133	"	"	"	"	"	16	4	448	-
134	"	"	"	5/8	5½	32	3	528	4
135	"	"	"	3/8	"	"	2	352	-
136	"	"	"	1/4	10	"	1	320	-
137	"	"	"	5/8	8	"	3	768	-
138	"	"	"	3/8	"	"	2	512	16
139	"	"	"	5/8	6	"	3	576	-
140	"	"	"	3/8	"	"	2	384	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
141	F2	6	38	3/8	10	32	1	320	2
142	"	"	"	5/8	$9\frac{1}{4}$	"	3	888	-
143	"	"	"	3/8	"	"	2	592	6
144	"	"	"	5/8	8	16	12	1536	12
145	"	"	"	1/2	"	"	3	384	-
146	"	"	"	5/8	4	"	4	256	-
147	"	"	"	1/8	$8\frac{1}{4}$	"	6	792	3
148	H3	"	"	1/4	6	24	2	288	-
149	"	"	"	3/8	"	"	4	576	-
150	"	"	"	"	"	18	6	648	-
151	"	"	"	5/8	"	36	4	864	16
152	"	"	"	"	8	"	3	864	-
153	"	"	"	1/2	"	"	1	288	7
154	"	"	"	3/16	10	"	1	360	-
155	F1	5	35	1/4	6	24	4	576	-
156	H3	6	38	"	7	"	2	236	-

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
157	HE	6	38	1/4	7	22	2	308	12
158	"	5	40	5/8	8¼	"	4	726	-
159	"	6	"	5/8	5½	"	4	485	-
160	"	"	"	1/4	10	"	1	220	-
161	F1	5½	35	"	"	24	1	240	16
162	"	"	"	5/8	8¼	"	4	793	-
163	"	"	"	"	5½	"	4	530	-
164	F3	6	40	1/2	10	20	6	1200	5
165	"	"	"	"	4	26	3	312	-
166	F2	"	"	"	2	28	3	168	-
167	"	"	"	"	"	9	6	108	8
168	F3	7	45	3/16	7	30	6	1260	-
169	"	"	"	3/8	"	44	6	1850	16
170	"	"	"	5/8	9½	"	8	3340	8
171	"	"	"	1/8	10	"	1	440	16
172	"	6	50	5/8	9½	"	2	835	16

Test No.	Material	Feed in/min	Speed RPM	Depth of cut	Width of cut	Length of cut	No. of passes	Sq. in.	Index blades
173	F3	6	50	3/8	9½	44	2	835	12
174	F2	"	40	3/16	10	14	4	560	-
175	"	"	"	5/8	3½	28	4	392	-
176	"	"	"	1/2	"	"	4	392	-
177	"	"	"	1/4	7	"	1	196	6

SUMMARY OF SYMBOLS

C = cutting speed at one minute tool life, (ft. per minute).

K_1 = direct labor rate + overhead rate $/minute. Includes operator labor, maintenance, power, depreciation, insurance.

n = exponent in cutting speed formula $VT^n=C$.

OBC = original blade cost ($per cutter).

= cost per blade x number of blades in head divided by number of uses per blade.

T = tool life in minutes.

TCC = tool changing cost ($per minute).

= tool changing time X K_1.

TGC = tool grinding cost ($per cutter).

= time to grind cutter x grinder labor + overhead rate.

TRC = tool replacement cost ($per cutter).

= OBC + TCC + TGC.

V = cutting speed (ft. per minute).

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